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SURFACE CONDITIONS AND STREAM FLOW.

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SURFACE CONDITIONS AND STREAM FLOW.

Popular opinion for years has been that floods are increasing in frequency and duration in many rivers of the United States. Until within a year, however, there had been no careful examination of records to see whether or not the popular opinion is based upon fact. The scientific bureaus of the Government which are directly interested in the matter had assumed that records had not been kept long enough on any river to show a change in the conditions of flow.

About a year ago it was thought worth while to look into the records to see whether any changes were discernible. The results were surprising. It was found that in many of the streams which take their rise in the Appalachian Mountains there has been a steady increase in the number and duration of floods during the past twenty or thirty years.

Following this discovery, a very general study was made of the change which has come about in the flow of a number of important rivers during the time for which records have been kept. Both the Geological Survey and the Forest Service have secured data on this subject, and the results warrant the statement that, unmistakably, floods are steadily on the increase in some of our most important rivers.[a] Particularly is this true of the rivers which rise in the eastern mountains. The increases seem to be greater on those watersheds where the condition of the surface has been the most changed. They are greatest in such streams as the Ohio, Cumberland, Wateree, and Santee, where the most forest has been destroyed, and least on the streams where forest conditions have been least changed.

It is true that in certain rivers an opposite tendency is to be seen. Floods have decreased and low waters have markedly improved. But a full inquiry into the conditions on these rivers also, as will be shown, seems to prove the rule that there is the closest kind of relationship between the surface conditions of a watershed and the flow of water through the stream which drains it.

The following table gives records regarding the flow of 10 important rivers of the United States on which careful records have been kept for periods ranging from sixteen to thirty-four years:

[a] Water Supply Paper 234, U. S. Geological Survey. Papers on the Conservation of Water Resources; Floods in the United States, by M. O. Leighton, Chief Hydrographer, U. S. Geological Survey.

CLASS I.—FLOODS INCREASED.

Name of stream.	Point of measurement.	Area of basin.	High-water stages taken in this table.	Low-water stages taken in this table.	First and second periods of record.		High-water data.						Low-water data.						Precipitation.		
					Years.	Duration.	Number of floods.	Days of floods.	Average times per year of floods.	Average days per year of floods.	Times of last period compared with first.	Days of last period compared with first.	Number of low stages.	Days of low stages.	Average times per year of low stages.	Average days per year of low stages.	Times of last period compared with first.	Days of last period compared with first.	Number of stations.	Mean (inches).	Mean annual increase or decrease (inches).
		Sq. mi.	*Ft.*	*Ft.*		*Yrs.*					*Per ct.*	*Per ct.*					*Per ct.*	*Per ct.*			
Potomac	Harpers Ferry, Va.	9,363	12	3	1890–1898	9	19	33	2.11	3.55	a36.80	a 72.70	54	1,351	6.00	150.00	a40.7	a 25.3	5	36.81	+.13
					1899–1907	9	26	57	2.77	6.33			76	1,693	8.44	188.00			5	37.97	
Monongahela	Lock4,Pennsylvania	5,430	20	7	1886–1896	11	30	55	2.73	5.09	a73.00	a 82.00	66	912	6.00	83.00	a36.33	a 7.33	6	42.25	−.08
					1897–1907	11	52	100	4.73	9.09			90	979	8.17	89.00			6	41.35	
Ohio	Wheeling, W. Va.	23,820	22	5	1882–1894	13	46	143	3.54	11.00	a28.25	a 31.50	79	1,333	6.08	112.50	a39.00	a 20.75	11	41.74	−.14
					1895–1907	13	59	188	4.54	14.40			110	1,609	8.46	123.70			11	39.90	
Cumberland	Burnside, Ky.	3,739	25	3	1890–1898	9	32	89	3.55	9.90	a34.40	a 14.60	61	1,261	6.77	138.00	a 6.50	a 27.00	3	46.27	−.54
					1899–1907	9	43	102	4.77	11.33			65	1,576	7.17	175.00			3	41.42	
Wateree	Camden, S. C.	5,135	20	6	1892–1899	8	46	147	5.75	18.37	a35.00	a 22.00	115	1,164	14.37	145.50	b44.30	b 56.40	3	45.46	+.25
					1900–1907	8	70	187	7.75	23.50			64	508	8.00	63.50			3	47.48	
Savannah	Augusta, Ga.	7,300	20	6	1890–1898	9	47	116	5.22	12.77	a28.40	a 46.50	70	566	7.70	63.00	b41.00	b 48.00	3	48.12	−.17
					1899–1907	9	58	170	6.44	17.77			41	292	3.56	32.00			3	46.58	
Tennessee	Chattanooga, Tenn.	21,418	24	2	1874–1890	17	32	173	1.88	10.18	a 3.13	b 20.80	71	902	4.17	53.00	b22.53	a 8.86	5	53.17	−.37
					1891–1907	17	33	137	1.94	8.06			55	982	3.24	57.70			5	46.83	
Allegheny	Freeport, Pa.	9,220	16	2	1874–1890	17	39	92	2.29	5.41	a35.90	a 42.40	99	1,747	5.82	102.70	b 8.10	a 35.00	4	41.65	−.32
					1891–1907	17	53	131	3.12	7.70			91	1,136	5.35	66.80			4	36.17	

CLASS II.—FLOODS DECREASED.

Wabash	Mount Carmel, Ill.	26,300	15	3	1890–1898	9	21	351	2.33	39.00	b 9.50	b 20.50	38	1,365	4.22	152.00	b15.75	b 15.00	5	39.54	−.40
					1899–1907	9	19	279	2.11	31.00			44	1,160	4.93	129.00			5	35.99	
Red	Arthur City, Tex.	40,200	20	4	1892–1899	8	19	87	2.37	10.87	b16.00	b 30.00	49	826	6.12	103.25	b83.60	b 74.80	5	31.80	−.24
					1900–1907	8	16	60	2.00	7.50			8	208	1.00	26.00			5	29.86	

a Increase. b Decrease.

THE TENDENCY IS TOWARD INCREASED FLOODS.

If the period during which the records have been taken on each of these streams be divided into two equal parts and a comparison be made of flood conditions for those parts, we find that 8 of the 10 rivers show greater floods in the last half than in the first half. The 8 rivers which show increased floods are the Potomac, at Harpers Ferry, W. Va.; the Monongahela, at Lock 4, Pennsylvania; the Ohio, at Wheeling, W. Va.; the Cumberland, at Burnside, Ky.; the Wateree, at Camden, S. C.; the Savannah, at Augusta, Ga.; the Allegheny, at Freeport, Pa.; and the Tennessee, at Chattanooga, Tenn. All of these streams, it will be noted, have their source waters in the Appalachian Mountains.

On the Potomac River, for which measurements are given for eighteen years, the number of floods during the first half of the period was 19; during the second half, 26; while the number of days of flood in the first half was 33, and in the second half, 57.

On the Monongahela River measurements are given for twenty-two years. During the first half of the period there were 30 floods; during the second half, 52. The number of days of flood during the first half of the period was 55; during the second half, 100.

On the Ohio River measurements are given for twenty-six years. During the first half of the period there were 46 floods; during the second half, 59. The number of days of flood during the first half was 143; during the second half, 188.

On the Cumberland River measurements were given for eighteen years. During the first half of the period there were 32 floods; during the second half, 43. The number of days of flood during the first half was 89; during the second half, 102.

On the Wateree River measurements have gone on for sixteen years. In the first half of the period the number of floods was 46; in the second half, 70. The number of days of flood in the first half of the period was 147; in the last half, 187.

On the Savannah River measurements have continued for eighteen years. During the first half of the period the number of floods was 47; during the second half, 58. The number of days of flood during the first period was 116; during the second half, 170.

On the Allegheny River measurements are given for thirty-four years. During the first half of the period there were 39 floods; during the second half, 53. The number of days of flood during the first half was 92; during the second half, 131.

On the Tennessee River measurements have been taken for thirty-four years. During the first half of the period there were 32 floods; during the second half, 33. The number of days of flood during the first half was 173; during the second half (in this case there was a falling-off), 137.

Mr. M. O. Leighton, chief hydrographer of the United States Geological Survey, has during the past year made an elaborate study of the floods in the Tennessee River.[a] In this study Mr. Leighton has isolated so far as possible the days of rain storm of sufficient magni-

[a] Floods in the United States, by M. O. Leighton, chief hydrographer, U. S. Geological Survey.

tude to produce floods, and on this basis has made a comparison of the floods of the two halves of the period. Although the number of days of flood was less during the last half of the period than during the first half, Mr. Leighton shows that the precipitation decreased in an even greater degree. The results of this close analysis show that the diminution of the precipitation has been more than sufficient to account for the diminution of the floods. The natural result is that in proportion to the rainfall, floods have increased, the percentage of increase being 18.75 in the last half of the period as compared with the first half. This study is undoubtedly the most complete and authoritative that has ever been made of any American river, and it seems conclusive.

The low-water stages of a river are never a safe criterion on which to judge its real condition. A slight change in the bed of a stream may considerably affect the low stage at the point where the measurements are taken, though the real condition of the stream may not be changed in the least. In the same way a stream may actually raise its bed by silting, and thus the low-water stage may be increased while the actual condition is worse than at first. A study of the low-water data of the above table shows that intensified low-water conditions as signified by the measurements do not correspond in all cases with intensified flood conditions. Of the eight streams above referred to, four show apparently intensified and four apparently ameliorated low-water conditions. But for the reasons just stated, these records can not be depended upon as having any real significance in showing the actual flow.

The constant increase in the frequency and duration of floods in these streams appears not to be due to change in precipitation. In two cases there has been a slight increase in precipitation. These are on the Potomac watershed, where, as the table shows, there has been on the average 1.16 inches more rain in the second half than in the first half of the period. On the Wateree there was an increase of 2.02. On all of the other watersheds there has been a decrease ranging from 0.90 of an inch on the Monongahela to 6.34 inches on the Tennessee. It is thus clear that while floods have greatly increased in these streams the tendency has been toward decreased precipitation.

While the record is given for only eight streams which show increased floods, it must not be understood that these are the only streams which show this tendency; rather, they are examples—particularly they are examples of streams having their source in the Appalachian Mountains. They have been given because their records are more complete and longer than those for other streams. The records of most other streams of the region, so far as they are sufficient to show a tendency, indicate the same progressive change toward increased floods. For example, this is true of the Alabama River, of the Connecticut, of the Muskingum, and of the Congaree.

WHAT HAS CAUSED INCREASED FLOOD CONDITIONS?

Since it is apparent from the records that flood conditions have greatly intensified in many streams during the past two or three decades, it is important to consider the possible causes. Several factors are known to have an important influence upon stream flow. Chief among these are climate, topography, geology, natural or artifi-

cial reservoirs, soil, and ground cover. Climate must be understood as embracing precipitation and evaporation, with whatever influences them—notably wind, humidity, temperature, and altitude. It is best to consider precipitation and evaporation separately, for they act in opposite directions and produce opposite effects.

PRECIPITATION.

It is, of course, apparent that precipitation must modify stream flow in a vital way, because no water can flow through the streams that does not first come down from the clouds. The amount of precipitation varies greatly from year to year. The amount for one year may be twice as great as for another in the same place, and at one point it may greatly exceed or fall short of that occurring a few miles away. While varying in a marked degree for short periods, precipitation becomes much more nearly constant through a long period.

If the precipitation had correspondingly increased over the Appalachian Mountain region, then it could be said that the greater and more frequent floods are due to that. But the figures which are given show that on only two of the eight watersheds mentioned in the table has there been any increase, and there by small amounts, while in the other six there has been a decrease, which in the case of one stream, the Tennessee, amounts to an average of 6 inches. The real tendency of the precipitation over these basins would therefore be to decrease flood conditions. Consequently, we must conclude that the increased flood conditions are in no degree due to precipitation.

EVAPORATION.

Taking the United States as a whole, less than half of the precipitation is said to pass through the rivers to the sea; the other part after a longer or shorter period, and after serving one purpose or another in nature's economy, goes back to the air through evaporation, except that portion which flows through underground courses to the sea.

Evaporation is fundamentally influenced by temperature, air pressure, wind, and humidity, and affects in a vital way both the regularity and amount of run-off of the streams. The Connecticut and Wateree rivers have about the same average annual precipitation—45 inches per year. Of this amount the run-off from the Connecticut watershed is 29 inches; from the Wateree watershed it is less than 18 inches. The difference is due to increased evaporation on the Wateree, where the temperature averages much higher. It is during the prolonged heated periods, which are often dry periods, that evaporation has greatest influence. It undoubtedly affects as much as any other factor the low-water stages of the streams, yet by its very nature it can not much influence floods, because they rise quickly and are never of many days' duration. There is not time for much water to evaporate. Hence we can put aside this climatic influence just as in this case we have put aside precipitation. We must look elsewhere for the cause.

TEMPERATURE.

Temperature, while influencing stream flow indirectly, through evaporation, also influences it directly. For example the upper watershed of the Monongahela River, in West Virginia, may be considered: It is February, and there have been several weeks of cold weather; the ground, which is bare of snow, is frozen solid. There comes a heavy fall of snow, or perhaps several, bringing the snow cover to a depth of 12 to 18 inches. Within a few days the weather moderates and a prolonged rainy period follows. The first rain is caught by the snow and little escapes. But as it continues to come, it melts the snow so that the water from the snowfall and the rainfall is concentrated upon the surface at one time. If the ground were not frozen, much of it could be absorbed and distributed downward, but in the case we have assumed the earth is frozen solid, so that no water, or at least but little, can be absorbed. The whole volume is liberated on the surface and races away from the smaller streams to the larger, and at last, gathering in immense quantity, it overtaxes the channel of the main river and inundates the entire valley. It is this condition of rain, snow, and temperature operating together which brings about some of the greatest floods. A flood resulting from such a cause is not likely to occur more than once a year in any stream, and several years may pass without flood on a given watershed from this combination of causes. It can not be said that floods from this cause show any progressive change, and consequently we can not ascribe to this cause the increased flood conditions in the rivers now under consideration.

TOPOGRAPHY AND GEOLOGY.

A region's topography largely influences its run-off. Steep slopes and sharp ridges shed water quickly. A flat surface causes it to flow away more slowly.

Likewise, geology has a great deal to do with the drainage of any region. When rain has fallen and has passed through the soil cover and the soil it comes in contact with the rocks which lie beneath. In obedience to gravity it will penetrate as deeply as possible. Considering the depth to which it can go and the quantity in which it can be stored, the earth forms a great storage reservoir which tends on most watersheds to have a strong influence toward steadiness in the flow of streams. While topography and geology are important factors in considering the amount and character of run-off when one stream is compared with another, they are of no consequence when one is considering the condition in the same stream during two different periods, because they are subject to no appreciable variation. Both the topography and the geology of any given stream may be said to be constant, and so are not of importance in considering what has caused a changed condition of flow in any particular stream.

NATURAL AND ARTIFICIAL RESERVOIRS.

Some streams have on their watersheds great lakes which gather and hold immense volumes of water. A good example is the Merrimac River. On one of its important tributaries is that fine body of water, Lake Winnepesaukee; on another is Squam Lake, and, in

addition, there are many smaller ones. Every natural reservoir of this kind tends to equalize the flow of the stream it feeds, because when its level is rising it is gathering in storage to pay out gradually the water which would otherwise run off at once. Moreover, on many of the lakes, especially on those in New England, dams have been built at the outlets. By this means the water of the whole surface has been increased a number of feet in depth. In dry times when it is needed this water is emptied out. A large portion is thus taken off of the crest of each flood and added to low waters. Then, too, men may construct reservoirs where there were none before. It is considered feasible in some streams to construct such extensive reservoir systems as to store a large part of the flood waters. If this can be done, the flow of the streams can be made for all practical purposes even throughout the year.

If at the headwaters of the rivers under consideration in this paper there had been great lakes or swamps which had been drained during the period under consideration, it might well be said that the influence of that action would be sufficient to cause a difference in the run-off of the streams. But, except in the case of the Wabash, there have been no changes of this character. There are on these streams no important natural lakes, and no reservoirs of great extent have been developed. Consequently, this factor also is insignificant.

SOIL.

Though the topography and geology of a watershed change too slowly to be readily observed, there are other factors in which changes may be rapid, radical, and of great importance. One such factor is soil. The soil, when considered as a factor in controlling run-off, is a complicated and delicate apparatus. It works admirably when in good condition, but it is easily deranged and is liable to severe and fundamental injury, by which its action on storm water may be lessened or almost entirely destroyed. Mistreatment frequently produces results of a serious nature in the drainage of a watershed.

The mineral soil is composed of disintegrating rock that has broken down by the slow process of weathering. Deep mineral soils, if they have not accumulated from transported materials, represent a long period of rest, during which the surface has been free from erosion, while the disintegrating rock beneath has added little by little to the depth. Upon the mineral base, and more or less mixed with it, is the humus, which owes its existence to organic matter mostly vegetable, which has decayed and added the accumulated remnants to the mineral soil. Humus vastly increases a soil's capacity to absorb and store water.

The important work which soil performs in regulating the run-off for a region is easily understood. If the soil is present in sufficient quantity and good condition, that is, is porous and well supplied with humus, it readily absorbs storm water at the surface and passes it on downward through the underlying rocks and strata. Although these rocks themselves change but little, their storage of water is regulated by the soil and varies with its changes. If the soil is hardened or removed, the amount of water which can be taken in is correspondingly reduced and the amount which is thrown off over the surface

into the streams correspondingly increased. A watershed without soil or with a soil which does not readily perform its normal functions, results in erratic streams, which are usually agents of destruction rather than of use. The consideration of the flow of any stream should therefore take particular note of the soil and of the changes in its capacity for water storage.

GROUND COVER.

Scarcely separable from the soil itself is another factor of equal or greater importance in the disposition of water. This is the ground cover, or, to speak of it more particularly, the condition of the surface of the ground; that is, whether it is barren rock or clay, pasture land, cultivated land, or forest.

The condition of the surface does not influence very much, so far as known, the amount of water which falls. It is claimed by some that the precipitation is greater in the forest than on unforested land, and the figures given in the table at the beginning of this paper seem to indicate a tendency toward lessened precipitation on those watersheds which will presently be shown as having a decreased forest area. However, it is not intended at present to lay any stress upon that point. If the influence of the various factors which affect stream flow have been correctly stated, none of them is sufficient to have caused the increased floods. The natural conclusion is that the increase must be due to changes in the ground cover, or to the ground cover in conjunction with changes in the soil. Is the influence of the ground cover and of the soil sufficient to have caused the results?

It is generally agreed by those who have studied the subject most thoroughly that the forest offers the best conditions for absorption and underground storage. Next to the forest comes well-cultivated farm land; then meadow and pasture land; while the worst conditions of all are to be found on barren surfaces of stone, clay, or gravel, which because of infertility are unable to support growth of any kind.

The reasons why the forest offers the best conditions for absorption and ground storage are several. It does so, in the first place, because the foliage of the trees forms a storage place from which water drips slowly to the ground for a considerable length of time after each rain; because the complex layer of brush, leaves, weeds, mosses, and vines, all in a more or less advanced stage of decay, becomes filled with moisture with each heavy rain and holds it for a considerable time; because, also, the surplus water so stored continues to be absorbed by the upper humus-filled layers of earth; because, further, the temperature is lower and the air more humid in the forest than in the open; finally, because the snow lies there much longer. To these reasons must be added the mechanical power of the roots to go deep into the soil and break up the rocks, thus forming channels for the ready entrance of water into the earth.

On a level or slightly inclined surface a well-tilled soil may be as effective in absorbing and holding water as a forest soil. Where the slope exceeds 10 per cent, cultivation does not long go on before erosion sets in, and erosion if unchecked will remove the soil and gully the surface until all fertility has gone and all protective power is lost. Agriculture under right conditions may be an effective means

of stream protection; under wrong conditions it may be the greatest menace to the even flow and usefulness of the streams.

THE PRINCIPAL CAUSES OF INCREASED FLOODS.

Undoubtedly it is the clearing away of the forest on the mountainous watersheds of the streams which have been described that has caused the great increase in frequency and duration of floods.

It is a known fact that the forests on these several watersheds have been cut away with great rapidity during the past thirty years. European conditions probably offer no parallel to the rate at which these watersheds have been cleared to make way for the rapid advance of agriculture and to supply the great manufacturing industries with the wood which they require. Forest lands, which offer the best possible conditions for soil absorption and underground storage, those great regulators of stream flow, have been changed to poorly tilled agricultural lands, which are not so good. Then these agricultural lands after a few years have been exhausted and their soil eroded into deep gullies. Finally, many of them have been turned into pasture or even entirely abandoned because they reached a condition where they could not support even a growth of grass and weeds. The best condition has been changed to the very worst condition.

Again, repeated burning of forest lands has tended to reduce the thickness and value of the ground cover and to lessen the power of the soil to absorb and to store water. The extent of damage from fire, so far as water storage is concerned, is generally vastly underestimated. A forest fire strikes both above and below the surface. It injures or kills the trees, destroys the undergrowth and brush, and consumes the great forest sponge—the ground cover and the humus. The extent of the injury is, of course, not always the same. It is sometimes slight; sometimes very great. Repeated fires tend to every kind of injury that can possibly be inflicted upon a forest soil, completely destroying the cover down to the mineral substances, and thus rendering it defenseless against the attacks of erosion. When that stage is reached, it may be depended upon that the run-off of the watershed has been profoundly affected and the regimen of the stream materially changed. The fact that forest fires have repeatedly swept over the watersheds of the streams under consideration makes it easy to believe that this factor, combined with the clearing away of the forest for agricultural purposes, has been the chief cause of the intensified flood conditions which the records now disclose.

THE VITAL PART OF A WATERSHED.

Considering the streams which drain the mountain regions, the most vital parts of the watersheds are the highest parts. It is there that precipitation is the heaviest, slopes the steepest, and the whole sum of conditions most influential. Therefore, so far as stream flow is concerned, the mountains are the portion which should be given the most judicious care. It is on the mountains that the best condition of soil and ground cover should be maintained. As the best ground cover, as has already been explained, is the forest, it is to the benefit of the streams that the mountains should be kept densely

forested, in order that the conditions for the absorption and retention of moisture may be as nearly as possible ideal. Under such conditions the course of the moisture will be one of continual interference from the time it reaches the crowns of the trees till it is in the stream. Every obstruction that can be placed in the way of the water aids by that much the even flow of the rivers. Under perfect forest conditions it is well-nigh impossible for any surface run-off to take place. The rain first comes into contact with the crowns of the trees, and the drops are broken more or less into spray. Some of the intercepted water runs down the trunks or drips from the branches. That which escapes interception by the trees encounters the undergrowth and brush immediately above the ground and is intercepted and retarded. As the water continues to make its way downward the ground litter offers the next obstacle. The water is caught up by the litter, and not until this has become saturated can the water pass on. If the rain continues for some time the litter becomes filled to its capacity, and then the humus begins to absorb the water which the litter can not hold. After a time it, too, becomes saturated. The water then gradually filters into and through the underlying soil. If this is deep it stores water in large quantity and then allows the surplus to pass to still greater depths, where it finally penetrates the rock strata and replenishes the great underground reservoir, from which it emerges later as springs, some of which may be far removed, even on the opposite side of the mountain, from the place where it has come in contact with the ground. If the precipitation is in the form of snow its course is substantially the same, but with a still greater delay in passing through the litter and entering the soil. The period that may elapse between the fall of rain and the appearance of water in a river varies from minutes to months or even years.

Even with the best regulated system of checking and storing the rainfall a condition may arise where, to a large extent, the effect of obstruction and storage in a forest may temporarily be lost. Severe and prolonged freezing may result in a sheet of ice in and over the upper soil, which prevents the entrance of water, and whatever falls in the form of rain must at once run off into the streams. Many rivers experience their worst floods when their drainage basins are frozen. On account of this condition it is impossible to claim that extreme floods will not come in a stream with a forested watershed. Fortunately the condition arises but seldom.

In such cases the conditions are similar to what they would be were the covering of the soil removed. The disastrous floods which come once or twice in a generation when heavy rains descend upon snow and frozen ground would probably be duplicated or surpassed yearly, or several times a year, were the soil stripped from the mountain regions. The heavy rains of summer which now fall upon a dense vegetation and hardly affect the larger rivers would then produce destructive floods.

A COMPARATIVE STUDY OF WATERSHED CONDITIONS.

The table on a preceding page gives data regarding the flow of 10 important rivers of the United States. It has not been possible to obtain for each watershed a record of the changes which are believed to be responsible for the increased flood conditions which the record

shows. It has been possible to make a detailed study of parts of the watersheds of two of the streams, the Cumberland and the Red.

A WATERSHED WHERE CONDITIONS HAVE GROWN WORSE.

The Cumberland River is a good example of how conditions have changed for the worse on some of these watersheds.

The drainage area of the Cumberland River above Burnside, Ky., comprises 3,739 square miles and lies in the heart of the Cumberland Mountains. The figures given in the table show that floods have increased in the Cumberland River at Burnside, Ky., in number from 32 in the first half to 43 in the second half, and in duration from 89 days in the first half to 102 days in the second half, while low waters have increased in times from 61 in the first half to 65 in the second half, and in days from 1.261 in the first half to 1.576 in the second half.

The removal of the forest on this watershed is progressing from three causes: (1) Clearing for agriculture; (2) lumber operations; (3) fires.

In 1890, when these measurements were begun, 21 per cent of the watershed above Burnside was cleared; in 1908 the cleared area had grown to 32 per cent. During the eight years from 1900 to 1908 clearing of forest for agricultural purposes went on on this watershed at the average rate of five-eighths of 1 per cent per year.

The total stand of timber on this part of the Cumberland watershed is 6,212,531,000 board feet. It is being cut away by lumbering alone at the rate of 4 per cent a year. These figures show that timber is disappearing on account of lumber operations eight times as fast as it is removed to clear land for farming purposes. In other words, supposing that lumbermen would cut clear as they go, 8 acres would be stripped for timber to 1 cleared for agriculture. The forest is not being cut clear. Instead, the lumberman is going over it time after time, picking out the particular kinds or classes of timber that he wants. First, he took the walnut and cherry; next, the white oak and poplar; now he is taking the chestnut and other kinds of oak. At the present time few tracts can be found from which one or more of the valuable timbers have not been culled. Other tracts have been stripped of nearly their entire growth.

At intervals of from one to five or six years fires run through the woods on the hills and mountains where the Cumberland River has its source. The fires are more frequent and destructive in districts where part of the timber has been cut and the refuse left on the ground. The dry ridges burn oftener than the coves, because the latter are sometimes too damp for burning. In times of prolonged drought, however, fires run through the ravines and coves where the densest growth is found. The fires are usually slow, and the damage to mature timber is not great, but the injury to the young growth is frequently excessive, and soil damage is serious. As a rule all seedlings and sprouts less than 4 or 5 feet high are killed, and, since fires come at intervals so frequent that the young growth can not attain a size above that, a large part of what would be the future forest, as well as the present ground cover, is destroyed. The surviving stand thus becomes thinner year by year, since it can not be replenished by

young growth, and since the mature trees are steadily falling by natural decay or by the ax.

Though the fires are slow and small, they burn the leaf cover and the upper layers of humus at each visitation. This removes or injures the porous surface, one of whose essential functions is to arrest the storm water falling upon the slopes and afford it an opportunity to sink into the ground. With the packing of the surface, after the litter and humus have been burned away, the water flows down the slopes and quickly reaches the streams, where, if in sufficient quantity, it produces flood conditions. Low water follows, because the hard ground is able to take in but little of the storm water to be paid out slowly afterward.[a]

The behavior of the Cumberland River shows a direct and positive relation between the run-off and the changed condition of the surface. The changes due to agriculture and lumbering can be definitely stated, but the extent and effect of forest fires are not subject to exact calculation. Yet undoubtedly all of these influences are active in producing the results as shown in the flood and low water records at Burnside. It is impossible that these results should be due to rainfall, because the rainfall was approximately 10 per cent less in the second half of the period. Since no other influences could have produced the result, there is no conclusion possible other than that the progressive floods and low waters have been due to the changes accomplished on the surface of the watershed.

A WATERSHED WHERE CONDITIONS HAVE GROWN BETTER.

The fact that man by his operations may decidedly change the regimen of a river is shown not alone by those streams whose flow has been influenced by clearing away the forest. It is shown, on the other hand, by streams whose watersheds of prairie soil compacted for ages by the trampling of buffalo, and more recently by cattle of the

[a] A more definite statement regarding the damage to humus by fire may be made for the upper watershed of the Potomac River. In Water-Supply Paper, No. 192, the U. S. Geological Survey shows that 838 square miles of the forest of this watershed had been so severely burned by repeated fires as to completely or almost completely destroy the humus. Other tracts aggregating twice that area had their soil severely damaged, but not to the point of complete destruction of the humus. Considered together, these burned-over lands have an area of over 2,500 square miles, or 27 per cent of the drainage basin above the point of measurement. Assuming that the humus of the uninjured forest soil of the Potomac basin would hold back for absorption 2 inches of water, and assuming that with the humus damaged as in this case the capacity of the soil for receiving water is lessened one-half, then 1 inch will be held instead of 2 inches, as formerly. In an area of 2,500 square miles, the inch of water, which formerly was absorbed but now flows away quickly, amounts to about 6,000,000,000 feet. During a heavy rain that quantity of water in excess of what would flow off quickly before would go at once to the streams.

The rating table for the Potomac at Point of Rocks, where the measurements were made, shows that when the river is at a 10-foot stage 61,000 cubic feet of water pass per second. The 6,000,000,000 cubic feet of extra flood water from the burnt forest is therefore sufficient, without a gallon from other parts of the basin, to maintain a 10-foot stage at Point of Rocks for thirty hours. The effect on succeeding low-water stages is a logical one. There is simply 6,000,000,000 cubic feet less of stored water to come gradually after the rains cease.

great ranches of the West, have been to a large extent brought under cultivation.

A stream which shows this tendency in an unmistakable way is the Red River, which forms the boundary for many miles between Texas and Oklahoma. On this stream records of flow are available for sixteen years. The number of floods in the first half of this period was 19; in the second half, 16. The number of days of flood in the first half was 87; in the second half, 60. Considering also the low-water periods of this river, we find that in the first half of the period there were 49 periods of low water; in the second half there were 8. In the first half the duration of low water was 826 days; in the second half, 208 days. A falling off in the rainfall occurred on this watershed, there being 1.94 inches less water per year in the second than in the first. Its drainage basin is, and has been during the time of its known history, practically without forests, only 1 acre in 10 being forested. In that respect it differs from all eastern and many western rivers whose basins are more extensively forest covered.

Why has the Red River constantly changed its flow toward steadiness and uniformity, while many other rivers have changed in exactly the opposite direction? The area of the Red River drainage basin above Arthur City, Tex., where the records were made, is 40,200 square miles, divided almost equally between Oklahoma and Texas. In this river, as in those before mentioned, the geology and topography have not changed. The precipitation has changed considerably in the direction of lessened rainfall, but not enough to account for the record. In soil conditions, and especially in the condition of the surface, however, the change has been marked. At the beginning of the period of measurement, in 1890, the country was for the most part occupied by large ranches. The native prairie sod had never been broken up.

On the part of the watershed lying in Texas there had been some settlement at an early date, but as late as 1900 no more than 12 per cent of the Texas part of the watershed had been improved. In the Oklahoma part of the basin, in the same year, the improved portion was 16 per cent. Development began most extensively about 1900. In southwestern Oklahoma, in that portion drained by the Red River, it was stimulated by the opening of Indian reservations to settlement. The Cheyenne, the Arapahoe, and the Wichita lands were opened, it is true, in 1890, but the real opening of the country to settlers came in 1901, when the Comanche, the Apache, and other Indian lands were opened, aggregating over 10,000 square miles, or more than one-fourth of the entire Red River basin above Arthur City. Another tract of over 8,000 square miles, the Choctaw and Chickasaw lands, began its development about the same time. A summary of these figures shows that in 1908 the Red River basin in Oklahoma had 10,200 square miles of improved land, instead of 3,284 square miles in 1900. Statistics are not complete for the Texas portion of this basin but the Texas portion has developed at about the same rate as the Oklahoma part. It is probable that the whole Red River basin above Arthur City, in Texas and Oklahoma, had 40 per cent of its land under improvement in 1908, instead of 14 per cent eight years earlier.

The results which have appeared in the form of change of the flow in the Red River are precisely what ought to be expected from the

changes in surface conditions. Theoretically, such results should appear, and as a matter of fact, they have appeared. The hardened prairie soil has been broken up and changed into cultivated fields over 40 per cent of the area, and thereby the absorptive capacity of the soil has been much increased. Over the remainder prairie fires have been kept out and better growth of grass secured. The extensions of cultivation and the improvement of the grass land has tended to equalize the flow of this river. The river's behavior has become better as the area of wild land has decreased. In other words, wild, barren land, being the worst condition for the protection of a watershed, and cultivated farm lands being next to forests the best condition, the change of a large part of the watershed from the worst condition to the next to the best condition has brought about this result.

The same law is thus seen to work on both the Cumberland and the Red River watersheds, but in different directions. On the Cumberland, as the watershed changes from the forest (the best condition for stream protection) to farm land, to pasture land, and even to barren condition (the very worst condition for absorption), the flow of the river is made more extreme, both as to floods and low waters. On the Red River watershed, beginning with a wild, almost barren, compacted surface, cultivation has changed the condition to that of permeable farm lands, which, next to forests, offer the best conditions. These two extremes exemplify, therefore, in different directions, the working of the same law—that there is a vital relation between the condition of the surface of the watershed and the manner of flow of the stream which drains it.

Approved:

JAMES WILSON, *Secretary of Agriculture.*

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